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VARIATION IN VOLUMETRIC EFFICIENCY OF AN ENGINE WITH VALVE LIFT

(POWER PLANT SECTION REPORT)

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VARIATION IN VOLUMETRIC EFFICIENCY OF AN ENGINE WITH VALVE LIFT.

OBJECT OF TEST.

The object of these experiments was to determine: (*a*) The effect of changes in valve lift on volumetric efficiency, (*b*) the effect of changes in compression ratio on volumetric efficiency, and (*c*) the effect of changes in valve lift on engine performance.

SUMMARY.

Although experimental difficulties lead to some doubt as to the accuracy of the absolute value of the test results, the following tendencies were clearly shown:

(*a*) Within the limits of this test volumetric efficiency increases with valve lift, the increase being more pronounced as the gas velocity through the inlet valves increases.

(*b*) Under similar conditions a compression ratio of 9.5:1 gives uniformly lower volumetric efficiency than a compression ratio of 5.4:1, except at the lower lifts with one intake valve.

(*c*) In the case of the engine used, the power output increases with increasing valve lift at all speeds from 1,200 to 2,000 revolutions per minute.

CONCLUSIONS.

Since the tests were confined to one particular size and type of cylinder, the results should not be considered as applying generally to all types of cylinders under all conditions. Furthermore, the tests to determine the effect of valve lift on volumetric efficiency were conducted by running the engine with external power and it is possible that the results might be slightly different had the engine been actually firing.

The reduction in volumetric efficiency with an increase of compression ratio is probably accounted for by the fact that the temperature at the end of the compression stroke is much higher in the case of the high compression ratio. This caused the valves and combustion chamber to assume a temperature considerably higher than was the case with the lower compression ratio, and the volumetric efficiency was correspondingly reduced. Whether the higher compression ratio would give a lower volumetric efficiency with the engine running has not been determined.

DESCRIPTION.

The cylinder in Figure 1 having four 1.75-inch valves in a flat cast-iron head, a steel barrel of 5-inch bore, and variable fulcrum valve rocker arms was designed and built for the purpose of ascertaining the effect of valve lift on the performance of an engine. The variable fulcrum arrangement of the valve rockers, as the name implies, provides an adjustment for varying the position of the rocker fulcrum, thereby varying the valve lift. This adjustment is made by turning the knurled knob shown in Figure 1 and can be made while the engine is running. This cylinder was mounted on the Universal test engine, set for a 6-inch stroke. (For a detailed description of the Universal test engine see Engineering Division Report No. 725.)

Figure 2 shows the complete set-up for the volumetric efficiency test. The engine was motored over on the dynamometer, and pumped air from the room through a 2-inch metering orifice (very carefully made in accordance with the instructions contained in Professor Durley's report in the A. S. M. E. Transactions, vol. 27) into chamber "A," which had a square cross section of the dimensions shown. From there it passed through an inch and a half orifice into chamber B, a steel cylinder of 15 cubic feet capacity, and then on through a 2-inch orifice into C, another steel cylinder of 4 cubic feet capacity. The engine pumped directly from C and the volumetric efficiencies were computed on the basis of the existing conditions of temperature and pressure in C. It was assumed that there was no temperature change in the air in passing from the room to C and the temperature was taken in C only. The depression at A was read with an inclined water manometer, and that at C with an upright manometer.

The literature on the general subject of volumetric efficiency of airplane engines is not very extensive. The following references on this subject are suggested.

Mr. H. R. Ricardo's paper delivered in January, 1922, at the winter meeting of the Society of Automotive Engineers in New York City.

"Aero-Engine Efficiencies," by A. H. Gibson, a paper delivered before the Royal Aeronautical Society of Great Britain, 1921.

The volumetric efficiencies obtained on the Liberty and Hispano engines are tabulated in Reports Nos. 102, 103, and 108 of the National Advisory Committee for Aeronautics, Washington, D. C.

LIST OF RUNS MADE.

The pumping runs were made at inlet valve lifts of 0.25, 0.297, 0.36, 0.42, and 0.48 inches with exhaust at maximum lift of 0.516 inches, at 1,200, 1,400, 1,600, 1,800, and 2,000 revolutions per minute. Readings were taken of temperature and of the manometers in A and C (see fig. 1).

The following pumping runs were made:

With a compression ratio of 9.54 to 1 (high compression):
- Three runs with all four valves in operation.
- Two runs with one intake and one diagonally opposite exhaust valve in operation.

With a compression ratio of 5.38 to 1 (low compression):
- Three runs with all four valves in operation.
- Two runs with one intake and one diagonally opposite exhaust valve in operation.

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A NAS-6 carburetor with a 1.75-inch choke with jets in place was used. No gasoline was fed to the carburetor. It was desired to ascertain the influence, if any, of volumetric efficiency on performance. Accordingly the air measuring apparatus was disconnected, and the carburetor intake opened to the dynamometer room and one friction and one power run, with the four valve low compression set-up, were made at the same valve lifts and revolutions per minute as were used in the pumping tests. The method was to hold the revolution per minute constant, and starting at the minimum valve lift increase it to the maximum and then decrease it to the minimum lift, taking readings of load at the valve lifts corresponding to those used in the volumetric efficiency tests. This obtained two sets of readings at each lift. In these runs the Stromberg NAS-5 carburetor with a 1⅜ inch choke was used. The gasoline was shut off for the friction run.

In all runs, pumping and power, the water outlet temperature was kept at 170° F.

METHODS OF COMPUTATIONS.

R. J. Durley's formula for the flow of air through a flat plate orifice gives the following:

$$W = .01369\, C\, d^2 \sqrt{\frac{iP}{T}}$$

where

- W=weight of gas discharged per second in pounds.
- d=diameter in inches of orifice.
- i=difference in pressures measured in inches of water across orifice.
- P=mean absolute pressure in pounds per square foot across orifice.
- T=absolute temperature of air Fahrenheit.
- C=experimental coefficient of discharge (0.600 in the case of a 2-inch diameter orifice).

Professor Durley in all of his experiments measured flow discharging in to the atmosphere, while in these experiments it was necessary that the flow be measured from the atmosphere. In Technical Notes No. 40 of the National Advisory Committee for Aeronautics, are the results of experiments made to determine the effect of the reversal of flow upon the discharge coefficient of Durley orifices, which indicate that the discharge coefficient is not reduced by more than 1 per cent, which is probably within the experimental error of Durley's experiments. Therefore, no attempt was made to correct for reversal of flow through the orifice in these experiments.

The pounds of air per second pumped, as obtained by Durley's formula, were changed to cubic feet per second under existing conditions of temperature and pressure at C. This volume divided by the piston displacement of the engine in cubic feet per second gave the volumetric efficiency of the engine.

ANALYSIS.

The apparatus used in the volumetric efficiency tests did not succeed in wholly dampening out the pulsations in the 4-valve arrangement of the engine. The inclined manometer measuring drop in pressure across the metering orifice remained quite steady, but pulsations sufficient to make an error as great as 1 per cent frequently occurred, particularly at higher speeds in the manometer at C. Care was taken to read the manometers only when they were steady. There were no pulsations in the 2-valve arrangement.

The results of the volumetric efficiency tests with the 4-valve arrangement, at the lower compression ratio, are shown in Figure 3. The volumetric efficiencies of three runs are plotted against valve lift and valve area for the different revolutions per minute, and a mean curve drawn through the points. (The area of opening per valve was taken as the area of a cylinder whose diameter is the inside diameter of valve seat and whose height is the maximum valve lift.)

The results of the same set-up with the higher compression ratio are shown in Figure 4. Figure 5 shows the resultant curves of Figures 3 and 4 plotted together on the same sheet for the purpose of comparison. It will be noticed that the volumetric efficiency of the low-compression runs is consistently higher than that of the high compression. On all high-compression runs of the 4-valve arrangement, sufficient heat was generated during the compression stroke to partially burn the oil which entered the combustion chamber. No such effect was noticed during the low-compression runs. The most probable explanation for the consistently higher efficiencies of the low-compression set-up is that an increase in temperature of the combustion chamber lowers the efficiency. It will be remembered that the amount of air pumped was measured in terms of the conditions of air at the carburetor intake.

Varying the valve lift seems to have the same effect in both high and low compression runs. There is but a slight increase in efficiency obtained in increasing valve lift at 1,200, 1,400, or 1,600 revolutions per minute, and at 1,200 and 1,400 revolutions per minute there is a slight decrease at the maximum lift, while there is a decided gain in efficiency at 1,800 and 2,000 revolutions per minute. This may be due to valve timing, for the efficiencies increase up to 1,800 revolutions per minute, where they begin to fall off. This might indicate that the combination of valve timing and manifold length was best suited for a speed in the neighborhood of 1,800 revolutions per minute. The valve timing obtained with the engine cold was as follows: Inlet opens 12° after top center, closes 32° after bottom center; exhaust opens 30° before bottom center, closes 6° after top center.

Figure 6 shows the results of high and low compression runs with the 2 valves in head arrangement. Here there is a decided increase in efficiency with increased valve lift at all speeds. At all speeds with the exception of 1,200 revolutions per minute the low-compression runs show a greater efficiency at the higher valve lifts.

In Table 5 are the loads measured on a 15.75-inch torque arm, obtained in running the engine under its own power, and also the loads required to motor the engine over at the same conditions of valve lift and revolutions per minute. Due to very frequent failure of the exhaust valves throughout the tests, using up the supply on hand, only one friction and one power run were obtained, the last valve breaking just at the completion of the power run.

The indicated load in Table 5 was obtained by adding the power and friction loads. An attempt was made with the data on hand to determine whether or not there was any relation between indicated power and volumetric

efficiency. Figure 7 shows the change in indicated loads, and volumetric efficiencies at the different revolutions per minute plotted against valve lift. All that can really be definitely determined from these curves is that both power and volumetric efficiency tend to increase with increase in valve lift.

Due to continual mechanical failures in the engine, the period of the test covered approximately two months, and in all cases several days necessarily elapsed between runs. In spite of the care with which readings were taken (and as has been previously stated, the pulsations in the manometers could account for an error of only 1 per cent), runs taken on different days failed to agree within sometimes as great an amount as 6 per cent.

In view of the fact that this investigation was confined to the performance of one size and type of cylinder unit, the results may not hold true for all types of cylinders under all conditions. Further, since the effect of valve lift on volumetric efficiency was determined by operating the engine as a pump (i. e., running it under external power), it is possible that slightly different results might have been obtained had the engine been actually firing.

The observed reduction in volumetric efficiency with increase of compression ratio may be accounted for by the fact that the temperature at the end of the compression stroke is much higher in the case of the high compression ratio. This caused the temperature of the valves and combustion chamber to be considerably higher than was the case with the lower compression ratio. The volumetric efficiency was correspondingly reduced, but whether this reduction would obtain with the engine running has not been determined.

The results of the comparison of the rates of increase of indicated load and the volumetric efficiency indicate merely that as valve lift is increased, indicated horsepower and volumetric efficiency also increase.

TABLE 1.—*Volumetric efficiencies.*

FOUR VALVES, LOW COMPRESSION RATIO, RESULTS OF THREE RUNS.

R. p. m.	Efficiencies at valve lifts.														
	0.250			0.297			0.360			0.420			0.480		
	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.
1,200	86.9	88.5	89.2	87.3	91.5	88.7	88.8	92.3	89.7	86.8	93.0	91.7	87.9	93.1	89.7
1,400	91.5	91.2	94.1	91.6	91.6	94.3	92.4	93.5	94.3	83.8	93.0	94.8	92.9	92.5	94.4
1,600	91.8	90.0	94.2	95.5	94.1	95.5	94.3	95.6	96.4	94.0	95.9	96.9	96.0	95.4	97.5
1,800	91.9	89.4	92.9	96.4	93.7	94.6	99.0	95.7	98.0	99.8	97.2	98.7	99.7	97.7	99.0
2,000	85.4	85.2	87.5	90.6	91.1	91.5	95.2	93.0	94.6	95.8	94.0	96.4	95.9	94.6	97.1

TABLE 2.—*Volumetric efficiencies.*

FOUR VALVES, HIGH COMPRESSION, RESULTS OF THREE RUNS.

R. p. m.	Efficiencies at valve lifts.														
	0.250			0.297			0.360			0.420			0.480		
	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 1.	Run No. 2.	Run No. 3.
1,200	88.9	85.9	86.4	88.1	85.2	88.5	88.9	86.5	88.5	89.5	87.7	90.6	88.9	87.7	89.3
1,400	90.0	86.5	90.4	89.0	88.0	91.0	90.8	89.4	91.0	90.1	89.6	91.8	89.4	89.0	92.6
1,600	91.6	88.3	92.5	92.1	88.3	94.0	93.3	91.9	94.0	93.8	92.3	94.0	93.9	93.0	94.4
1,800	91.8	86.4	93.6	94.0	90.6	95.8	96.5	92.8	98.7	97.2	95.4	99.0	97.2	95.3	99.6
2,000	86.6	83.8	89.0	90.8	88.2	92.3	93.5	90.0	94.6	94.0	93.2	94.7	94.0	92.8	95.0

Table 3.—*Volumetric efficiencies.*

TWO VALVES, HIGH COMPRESSION RATIO, RESULTS OF TWO RUNS.

R. p. m.	Efficiency at valve lifts.									
	0.25		0.297		0.36		0.42		0.48	
	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.
1,200	82.1	81.5	88.6	86.2	89.7	86.5	90.7	90.8	91.5	90.8
1,400	78.8	77.9	82.7	82.4	87.8	87.1	87.7	88.0	89.7	88.4
1,600	71.9	72.2	79.9	79.3	84.1	83.0	86.6	86.2	89.6	89.4
1,800	67.2	67.1	75.9	75.7	82.4	82.6	85.8	85.7	87.9	87.2
2,000	62.0	62.1	73.3	72.2	77.7	76.8	82.2	81.5	84.0	83.1

Table 4.—*Volumetric efficiencies.*

TWO VALVES, LOW COMPRESSION RATIO, RESULTS OF TWO RUNS.

R. p. m.	Efficiency at valve lifts.									
	0.25		0.297		0.36		0.42		0.48	
	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.	Run No. 1.	Run No. 2.
1,200	82.7	81.9	91.6	87.2	90.6	88.65	92.6	88.8	90.5	92.6
1,400	75.2	75.5	84.4	84.1	88.7	86.7	90.3	89.6	91.0	91.3
1,600	71.0	71.1	78.8	79.2	84.5	87.2	87.0	90.1	90.5	92.0
1,800	65.4	60.9	74.2	76.6	80.4	83.4	86.1	86.6	92.4	89.5
2,000	62.0	59.2	68.5	68.6	76.0	77.5	82.1	81.4	87.6	84.3

Table 5.—*Rates of change of indicated load and volumetric efficiency at various r. p. m. and valve lifts for the four-valve low compression ratio set-up.*

Valve lift (inches).	Power load (lb. at 15¾ in.).	Friction load (pound).	Indicated load (pound).	Per cent change indicated load.	Per cent change in volumetric efficiency.
1,200 R. P. M.					
0.25	66.05	16.40	82.45	0	0
.297	67.80	16.50	84.30	2.2	1.5
.36	68.05	16.45	84.50	2.5	3.0
.42	68.30	16.50	84.80	3.0	3.5
.48	69.20	16.70	85.90	4.2	2.6
1,400 R. P. M.					
0.25	66.05	17.10	83.15	0	0
.297	67.80	16.90	84.70	1.9	0.5
.36	68.70	16.85	85.55	2.9	1.6
.42	69.90	16.80	86.70	4.3	2.3
.48	70.00	16.90	86.90	4.5	2.8
1,600 R. P. M.					
0.25	60.50	19.75	80.25	0	0
.297	63.20	19.50	82.70	3.0	2.1
.36	64.80	19.45	84.25	5.0	3.8
.42	64.80	19.40	84.20	4.9	3.8
.48	65.90	19.40	85.30	6.3	4.3
1,800 R. P. M.					
0.25	58.20	19.45	77.65	0	0
.297	61.80	19.10	80.90	4.2	4.4
.36	62.70	19.20	81.90	5.5	7.1
.42	64.05	18.80	82.85	6.7	7.6
.48	64.30	18.80	83.10	7.0	7.9
2,000 R. P. M.					
0.25	52.80	20.45	73.25	0	0
.297	56.60	19.90	76.50	4.4	5.5
.36	57.40	19.80	77.20	5.4	9.3
.42	58.00	19.75	77.75	6.1	10.0
.48	58.90	19.90	78.80	7.6	10.0

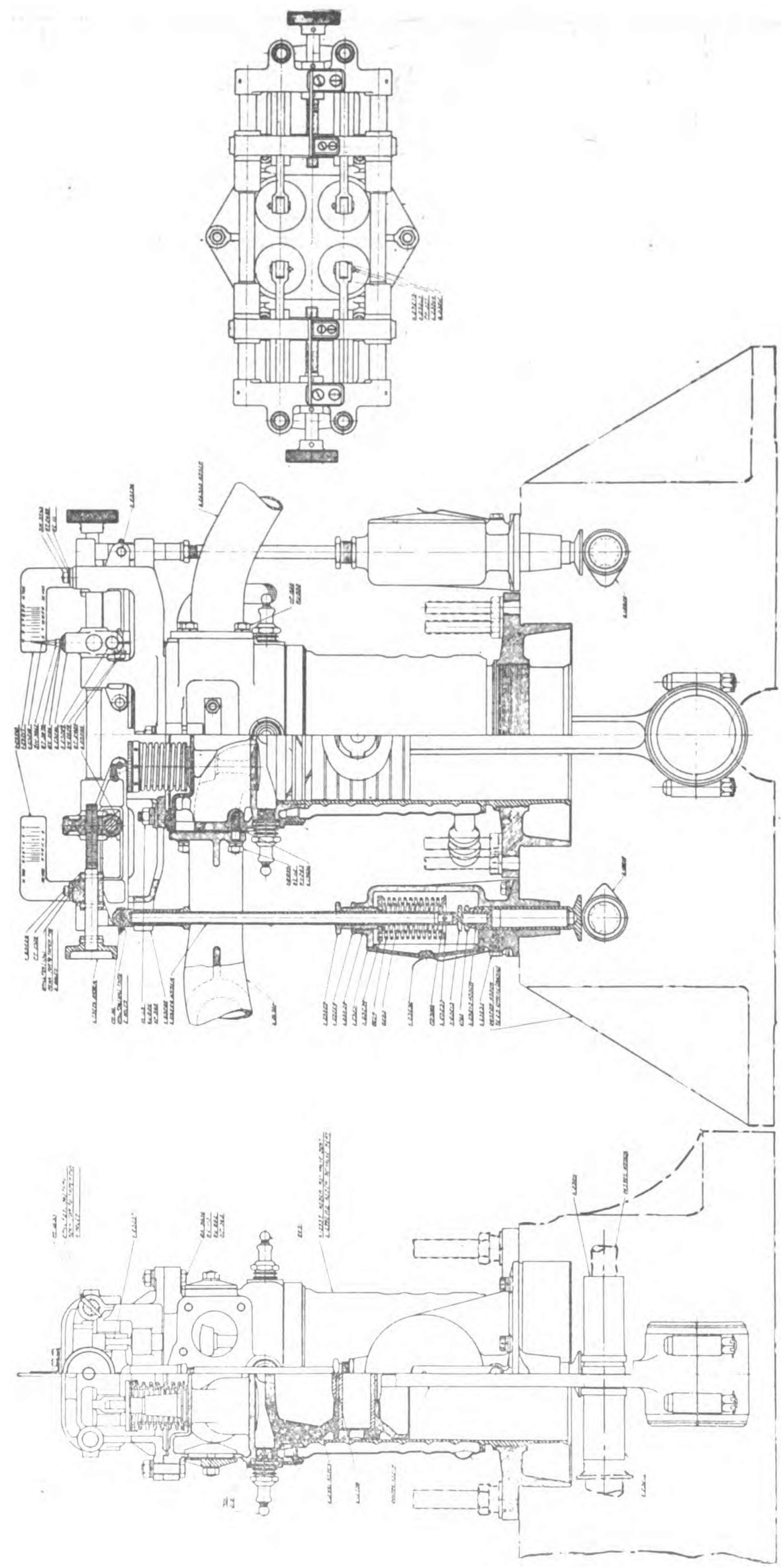

FIG. 1.—Volumetric efficiency test. Variable fulcrum valve mechanism assembly.

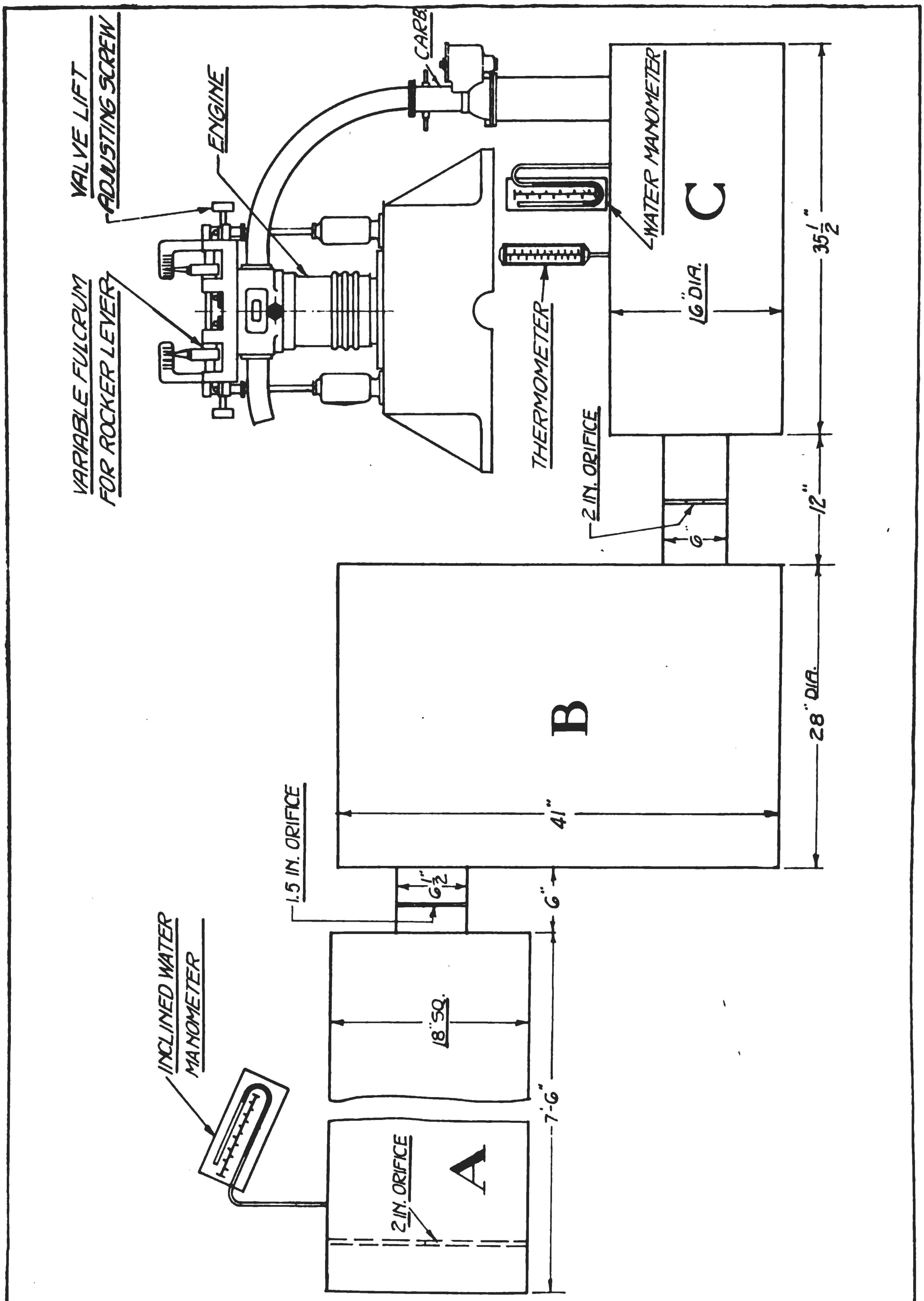
VALVE LIFT
ADJUSTING SCREW
ENGINE
CARB.
VARIABLE FULCRUM
FOR ROCKER LEVER
WATER MANOMETER
C
16" DIA.
THERMOMETER
2 IN. ORIFICE
6"
12"
35 1/2"
28" DIA.
B
41"
1.5 IN. ORIFICE
6 1/2"
6"
INCLINED WATER
MANOMETER
18" SQ.
7'-6"
A
2 IN. ORIFICE

Fig. 2.

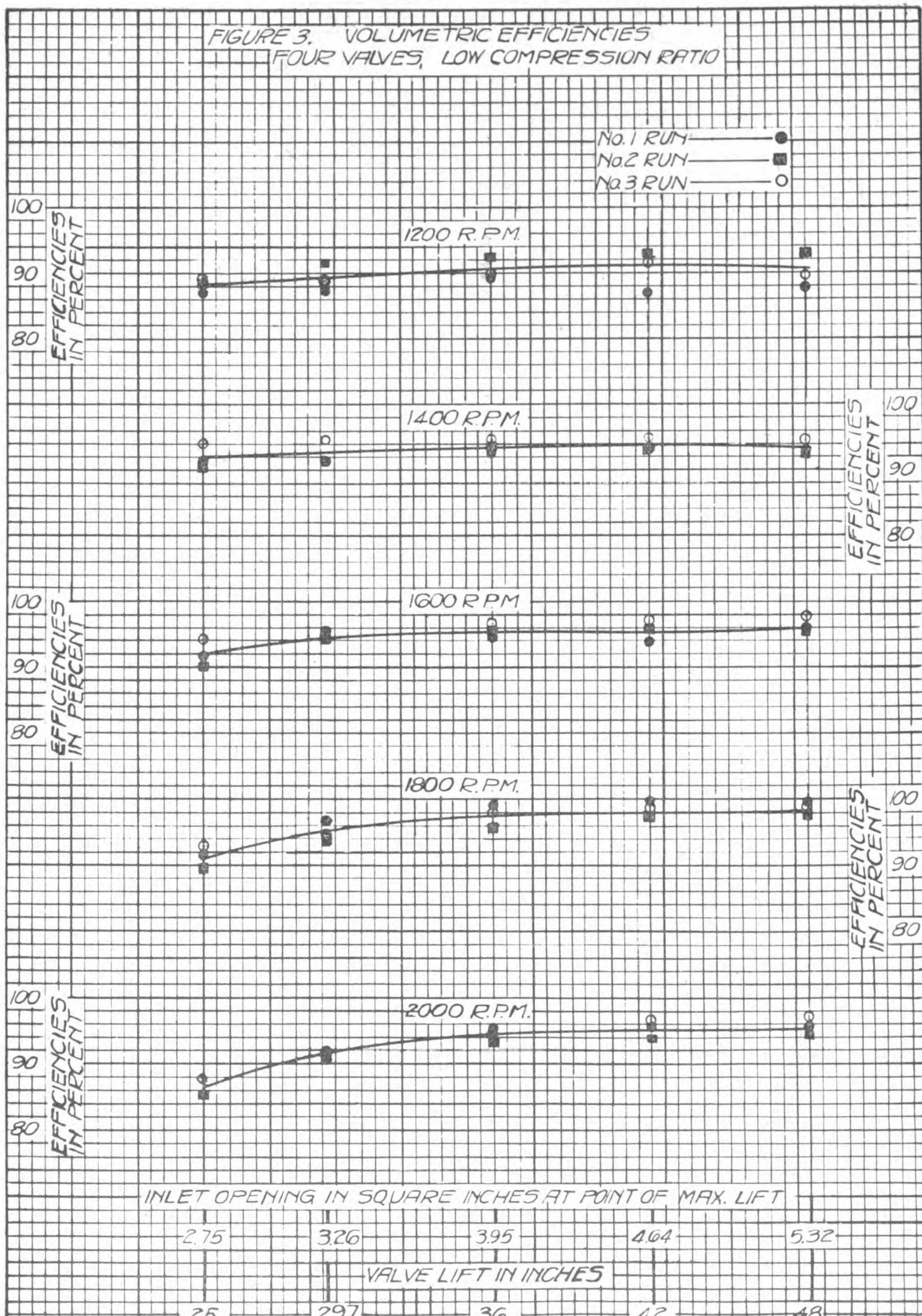
FIGURE 3. VOLUMETRIC EFFICIENCIES
FOUR VALVES, LOW COMPRESSION RATIO
No. 1 RUN
No. 2 RUN
No. 3 RUN
1200 R.P.M.
1400 R.P.M.
1600 R.P.M.
1800 R.P.M.
2000 R.P.M.
EFFICIENCIES IN PERCENT
100
90
80
INLET OPENING IN SQUARE INCHES AT POINT OF MAX. LIFT
2.75
3.26
3.95
4.64
5.32
VALVE LIFT IN INCHES
.25
.297
.36
.42
.48

FIG. 3.

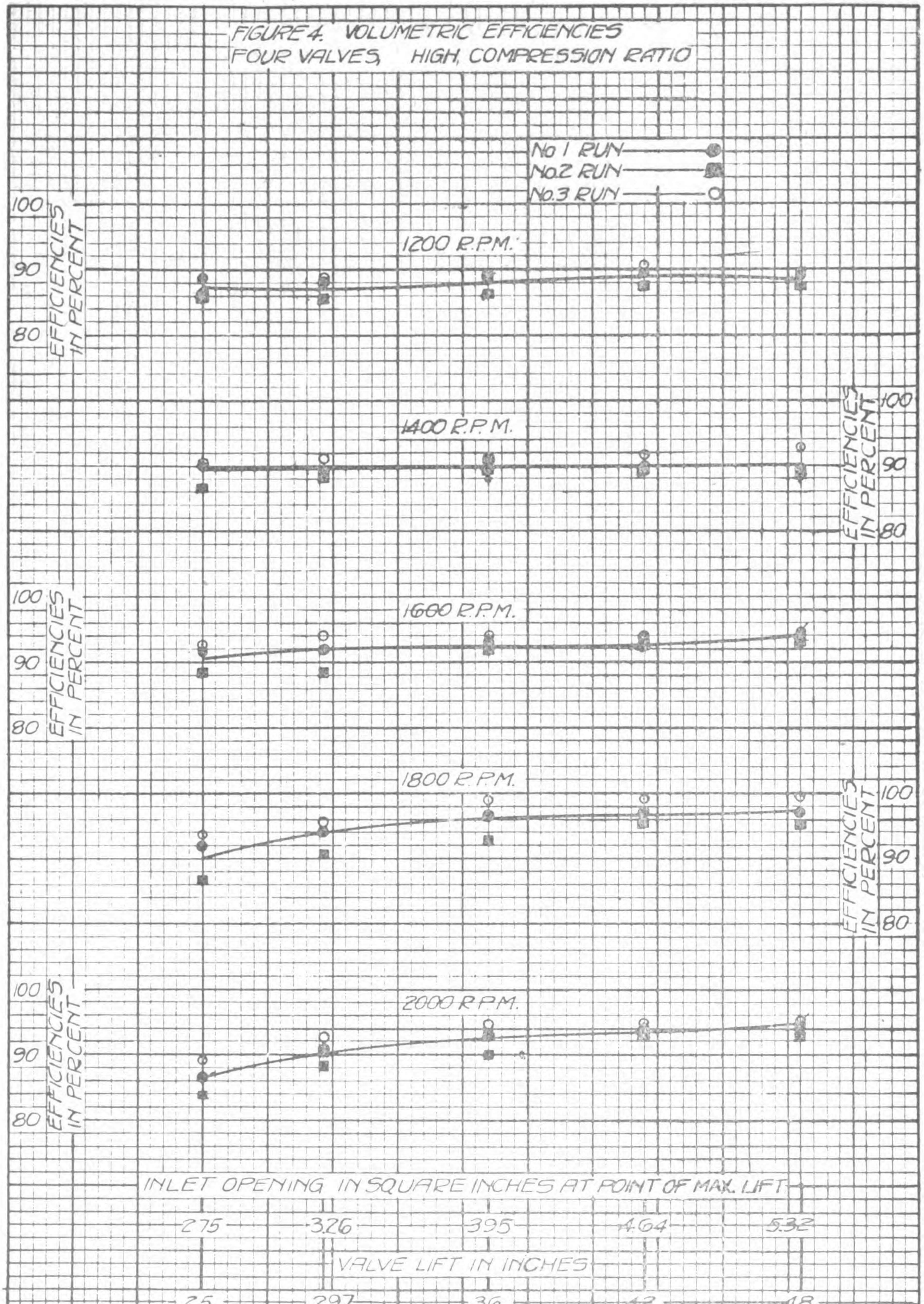
FIGURE 4. VOLUMETRIC EFFICIENCIES
FOUR VALVES, HIGH COMPRESSION RATIO
No 1 RUN
No.2 RUN
No.3 RUN
1200 R.P.M.
1400 R.P.M.
1600 R.P.M.
1800 R.P.M.
2000 R.P.M.
EFFICIENCIES IN PERCENT
100
90
80
INLET OPENING IN SQUARE INCHES AT POINT OF MAX. LIFT
2.75
3.26
3.95
4.64
5.32
VALVE LIFT IN INCHES
.25
.297
.36
.42
.48

FIG. 4.

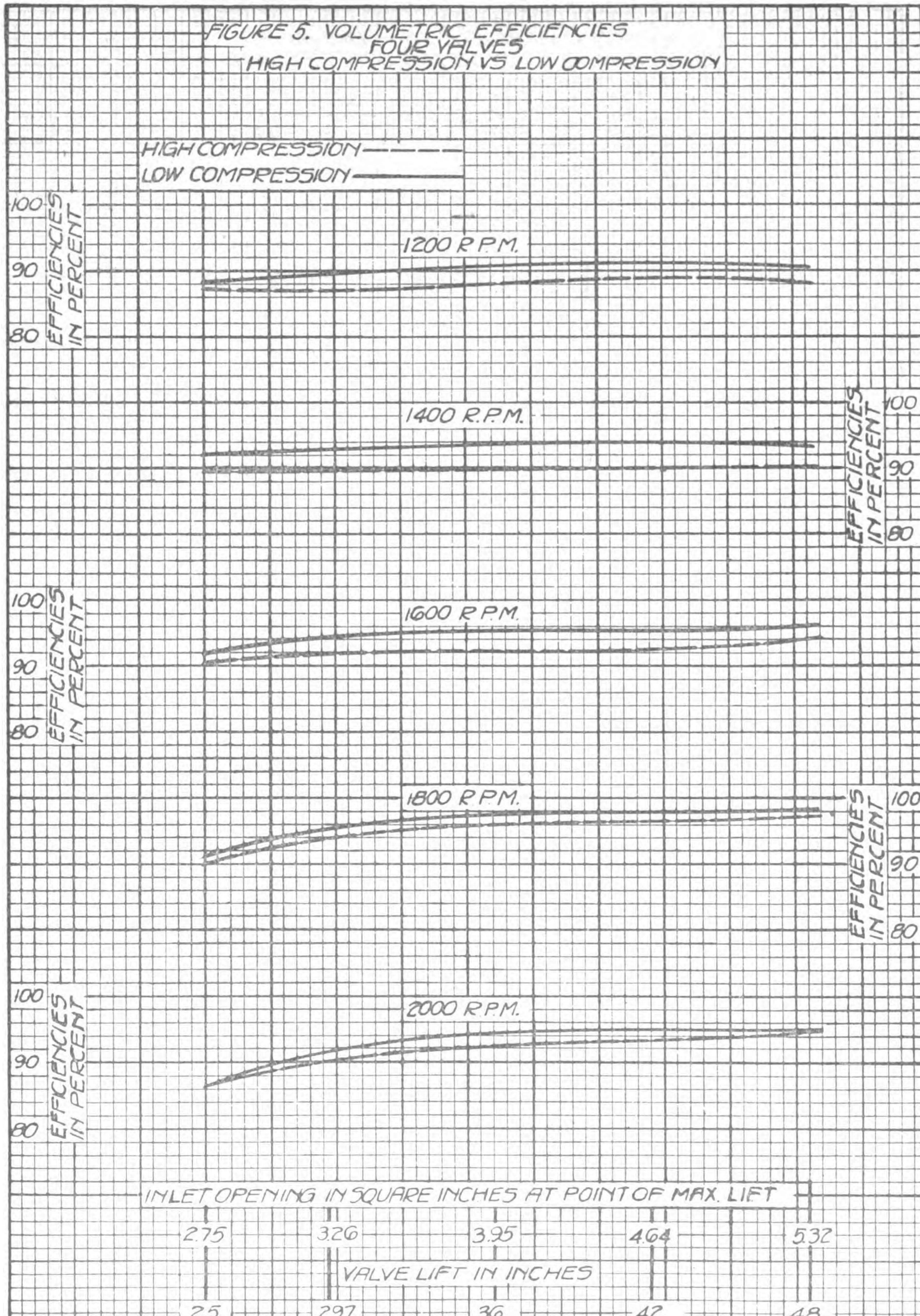
FIGURE 5. VOLUMETRIC EFFICIENCIES
FOUR VALVES
HIGH COMPRESSION VS LOW COMPRESSION
HIGH COMPRESSION
LOW COMPRESSION
1200 R.P.M.
1400 R.P.M.
1600 R.P.M.
1800 R.P.M.
2000 R.P.M.
EFFICIENCIES IN PERCENT
100
90
80
INLET OPENING IN SQUARE INCHES AT POINT OF MAX. LIFT
2.75
3.26
3.95
4.64
5.32
VALVE LIFT IN INCHES
.25
.297
.36
.42
.48

FIG. 5.

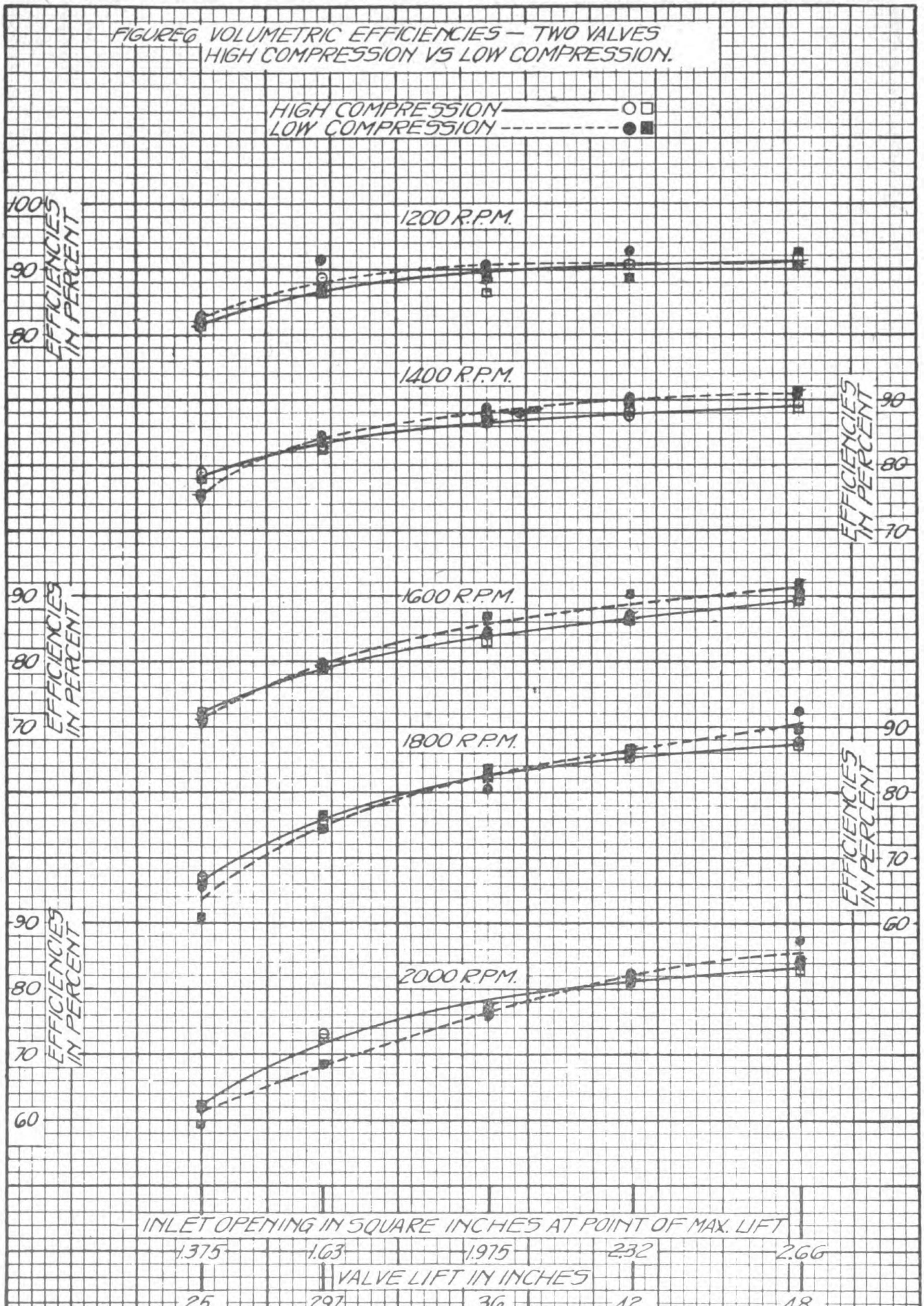
FIGURE 6 VOLUMETRIC EFFICIENCIES — TWO VALVES
HIGH COMPRESSION VS LOW COMPRESSION.
HIGH COMPRESSION
LOW COMPRESSION
1200 R.P.M.
1400 R.P.M.
1600 R.P.M.
1800 R.P.M.
2000 R.P.M.
EFFICIENCIES IN PERCENT
100
90
80
70
60
INLET OPENING IN SQUARE INCHES AT POINT OF MAX. LIFT
1.375
1.63
1.975
2.32
2.66
VALVE LIFT IN INCHES
.25
.297
.36
.42
.48

Fig. 6.

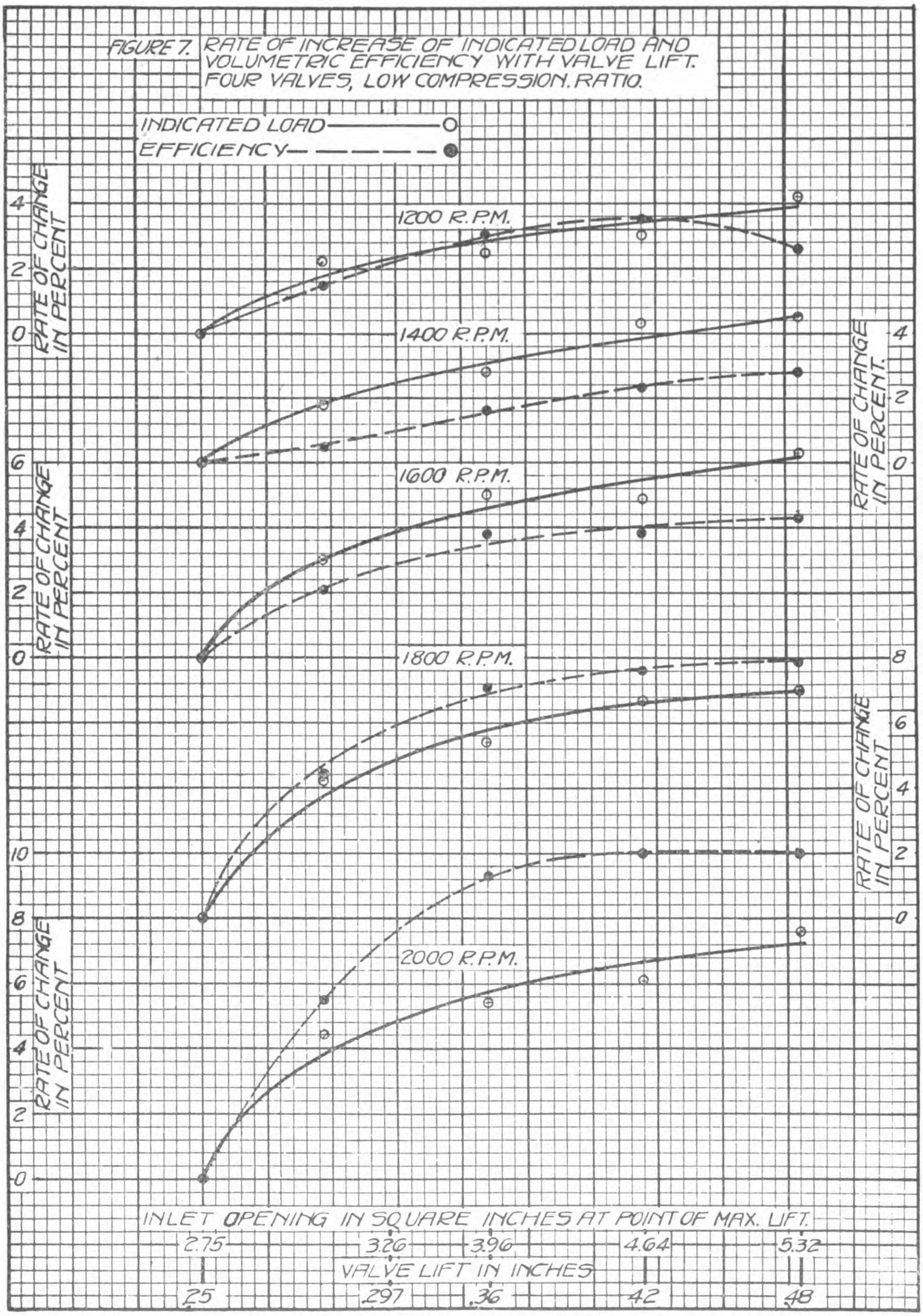

FIGURE 7. RATE OF INCREASE OF INDICATED LOAD AND VOLUMETRIC EFFICIENCY WITH VALVE LIFT. FOUR VALVES, LOW COMPRESSION. RATIO.
INDICATED LOAD
EFFICIENCY
1200 R.P.M.
1400 R.P.M.
1600 R.P.M.
1800 R.P.M.
2000 R.P.M.
RATE OF CHANGE IN PERCENT
RATE OF CHANGE IN PERCENT.
INLET OPENING IN SQUARE INCHES AT POINT OF MAX. LIFT.
2.75
3.26
3.96
4.64
5.32
VALVE LIFT IN INCHES
.25
.297
.36
.42
.48

Fig. 7.